Some Interplanetary Missions Using IEC Fusion Propulsion

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Outline

- Purpose
- Propulsion System Definition
- Vehicle Definition
- Mission Analysis Procedure
- Results
- Summary/Future Work

Purpose

- IEC fusion offers the possibility of very efficient space propulsion with substantial thrust
- Examine human travel to the planets in order to determine the impact this technology could have
    - Reduced travel time
    - Reduced fuel mass
- Travel via IEC propulsion is from Earth orbit to another planetary orbit. Propulsion to a planet's or moon's surface assumed separate.

References

- This work was summarized as part of a paper at STAIF 2000, "IEC Fusion: The Future Power and Propulsion System for Space," authors G.H. Miley, J. Nadler, I. Hrbud, J. Hanson, W. E. Hammond, and M. Coventry.
- All propulsion system data and vehicle masses obtained from Walter Hammond/Pace & Waite
- IEC Propulsion is also described in Chapter 7 "Propulsion Systems" of the forthcoming book: Hammond, Walter E., Design Methodologies for Space Transportation Systems, *AIAA Education Series Books*, John S. Przemieniecki, Series Editor, American Institute of Aeronautics & Astronautics, Reston, VA, 2001.

Propulsion System Definition

- "Baseline" and "far-term" cases considered
- Baseline
  - Propulsion module has six deuterium-driven IEC reactors operating at under breakeven conditions
  - Moderate-size IEC reactor operating past the breakeven point to power the six modules.
  - 25% deuterium and 75% hydrogen gas injected into the output deuterium plasma from a "jet mode" IEC device
- Far Term
  - All deuterium output plasma flow from six jet mode propulsion IEC reactors, which operate past the breakeven point
  - Additional power-producing IEC reactor not necessary

Propulsion System (cont.)

- Thrust
  - Baseline: 8,670 N
  - Far term: 34,680 N (baseline assumed 25% efficiency relative to far term)
  - Comparison: This thrust yields between 0.002 and 0.06 g acceleration for the missions examined. Chemical engines typically about 0.1 g; electric propulsion typically about 1×10^{-4} g
- Efficiency
  - Baseline: Isp (thrust/flowrate/g) = 70,500 sec (same flow rate as far term but 25% efficient)
  - Far term: Isp = 282,000
  - Comparison: chemical engines 300-440 sec, electric propulsion 3,000-10,000 sec

Vehicle Definition

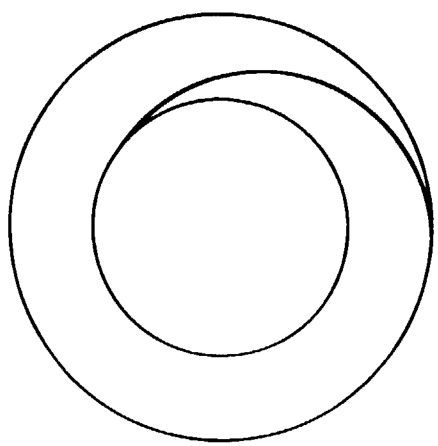
- Assume crew of 4
- Propellant tanks have 10% mass of propellant

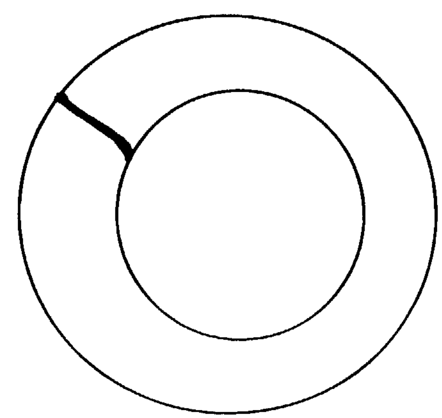
	Baseline			Far Term		
Parameter	Mars	Saturn	Pluto	Mars	Saturn	Pluto
IEC modules and power conditioning (kg)	6,000	6,000	6,000	6,000	6,000	6,000
Six nozzles (kg)	1,200	1,200	1,200	1,200	1,200	1,200
Driving IEC to power thrust modules (kg)	3,000	3,575	4,150	0.0	0.0	0.0
Crew and consumables (kg)	21,601	35,300	70,623	19,993	25,033	35,932
Structure (kg)	10,000	11,500	13,000	10,000	11,500	13,000
Contingency and reserves (kg)	10,000	10,000	10,000	10,000	10,000	10,000

- Comparison: Far-term Mars case is 47,193 kg; Apollo sent approx. 48,500 kg payload on translunar trajectory

Mission Analysis Procedure

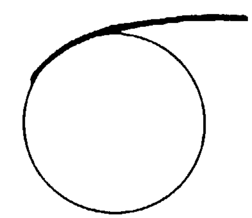
- Travel to the planets would be possible with very low propellant usage due to the high efficiency of these engines
  - Robotic missions could use very little fuel compared to present
  - Cargo could be sent ahead of astronauts this way
- We will examine travel in minimum time
  - Continuous thrusting
  - Nearly radial motion outward from Sun



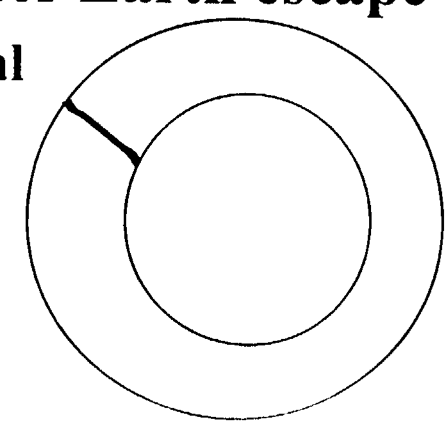


Mission Analysis Procedure

- Numerical integration assuming circular planetary orbits
- Depart Earth when target planet is in ideal location for arrival
  - Every 2 years for Mars
  - Every year for Saturn and Pluto



- Leave from low Earth orbit (burn along velocity vector to escape) and arrive in planetary orbit (burn along velocity vector)
- Thrust nearly radially outward from Sun after Earth escape
  - Component of tangential thrust to keep tangential speed equal to local circular speed
- Turn around at the right time to remove radial speed by the time of planetary arrival



Results

	Baseline			Far Term		
Parameter	Mars	Saturn	Pluto	Mars	Saturn	Pluto
Propellant tanks (kg)	1,962	11,238	35,158	873	4,285	11,666
Propellant (kg)	19,617	112,377	351,575	8,726	42,850	116,657
Final planetary orbit radius (planetary radii)	1.5	2.0	1.5	1.5	2.0	1.5
Initial Mass in LEO (kg)	73,379	191,188	491,704	56,791	100,867	194,454
Mass in destination orbit (kg)	53,765	78,803	140,121	48,064	58,011	77,789
Total travel time (days)	17.5	101.0	324.5	8.1	39.6	107.7
Time to Earth escape speed (sec)	46,536	130,791	356,282	7,051	14,291	29,712
Max speed achieved (km/s)	107	298	430	229	758	1,264
Max thrust angle from vertical (deg)	3.0	5.1	8.5	1.37	1.94	2.7

•Comparison: Mars robotic missions take 7-9 months to reach Mars; Cassini mission to Saturn takes 7 years to get there; direct mission takes about 6 years to Saturn; direct to Pluto is about 32 years (8 years to flyby only with Jupiter gravity assist)

Summary

- A space propulsion capability of this type would revolutionize travel in the solar system
  - Cargo ships and robotic missions would require very little fuel
    - Approx. 1/200 the fuel of chemical rockets for the baseline IEC case (savings is less if compared to gravity assist chemical rocket missions)
  - Human missions could either travel with little fuel expenditure or could arrive quickly at the planets
    - Trips to Mars become more like the Apollo trips to the Moon
    - Trips to Saturn take 1-3 months to arrive (vs 4-7 years now) and are much shorter than planned human Mars missions today

Future Work

- This simplified analysis included only transfers when planetary geometry is ideal

Earth-planet distance (Mkm)	Mars	Saturn	Pluto
Minimum	55	1197	4291
Maximum	396	1651	7522

- Travel to any of the planets should now be available at any time for incremental additional fuel
  - Opens up ability to return to Earth quickly if there are problems
  - Opportunity for increased interplanetary travel
- Next step is to calculate the optimal trajectories and mission plans for this travel
  - Keep-out zone around the Sun
  - A GSRP effort has been proposed to do this research